Division of forest fuel type areas of Heilongjiang Province by using GIS

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Abstract: Eight factors, including forest coverage, fuel load, species composition, elevation, monthly mean temperature, monthly mean relative humidity, monthly mean wind velocity, and monthly mean precipitation of fire season, were considered and the methods of weight, the cumulative probability, ARC/INFO technique, and raster-to-vector conversion were adopted in division of forest fuel type area. Firstly, the electronic maps of forest distribution and administrative divisions were built, then overlaid and transformed to the real-world coordinates. Finally, the forest fuel type areas of Heilongjiang Province including 81 counties were divided into five grades, accounting for 16%, 17%, 17%, 11%, and 38% respectively. The grade I fuel type areas with highest fire danger rating mainly distributed on Daxing'anling Mountains, Xiaoxing'anling Mountains, and Zhangguangcailing Mountains, the grade V fuel type areas mainly centralized on Songnen Plain, Sanjiang Plain, and other Plains, and other forest fuel type areas (grades II, III, and IV) were situated between plains and mountainous areas.

Keywords: GIS; Forest fuel type; ARC/INFO; Heilongjiang Province
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Introduction

Fuel type is defined as a discriminating combination of fuel factors. Fuel factors include species of trees, figure, size, configuration state, and other fuel characters which forecast the spreading rate of fire and manipulative degree of control under special combustion (CCFFC, 1976; Stocks, 1984). Particularly speaking, a fuel type is a discriminating fuel compound body that possesses enough intercommunity in characters and space distribution. Fuel type synthetically manifests habitat of plant type and the characteristic of forest structure adapting to environments, and decides to the structure of fuel configuration, density, physical and chemical characters. Features of fuel type include fuel load, size of particle, and density of volume, horizontal continuity, vertical distribution, and chemical element, which are quantified and synthetically analyzed. Based on these features, we could found forest fuel model, then classify fire danger ratings in order to instruct forest fire prevention, fire fighting and burning practice.

Fuel type is base of fire management and forest fire forecast, especially fire behavior. Different forest fuel types have different burning qualities and fire behavior. In the course of fire fighting, the arrangement of manpower and material resources and the use of fire tools and fire countermeasure should be decided based on forest fuel type. Fire behavior of fuel type can be forecasted in stabilization period, and this period can keep for a long time (Stocks, 1984). Therefore only based on forest fuel, the accuracy of fire forecast could be assured. Study and determination of forest fuel type can offer scientific basis for division of fire danger areas.

Study site

Heilongjiang Province is located in the northeast of China, between latitude 43°25′-53°33′N and longitude 121°11′-135°5′E, bordering Russia by Heilongjiang River on east and by Wusuli River on north, adjoining Inner Mongolia on the west and Jilin Province on the south. The total area of the Province is 4.54×10^5 km^2, accounting for 4.73% of China (Li *et al.* 1993). Mountainous regions account for 58.9% of the entire Province (middle mountains 4.4%, low mountains 20.4%, uplands 21.8%, mesas 1.8%, river valleys and alluviation plains 10.5%), and plains is 41.1%. For topography, south, north and central parts are higher, and east and west parts are lower. The water systems are Heilongjiang River, Songhuajiang River, Wusuli River and Suifen River, which are composed of 1700 rivers. Heilongjiang Province is in the middle of westerly vinds, with weather system moving from west to east. Two air masses, one is continental polar air mass originating from latitude 60°N, and the other is air mass of Pacific Ocean originating from latitude 30°N, are active in this region. The ectone of two air masses moves alternately in south and north with change of season. Different weather systems are formed with the movement of air masses. The types of soil include zonal soil (forest soil, grass soil, and forest-grass soil, etc.) and non-zonal soil.

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Forests of Heilongjiang Province are important part of northern forest zone of Eurasia, and the type of zonal vegetation belongs to coniferous forest of cold temperate zone and theropencedrymion of temperate zone. Forest mainly distributes in Daxinganling Mountains, Xiaoxinganling Mountains, Zhangguangcailing Mountains, Laoye Mountains, and Wanda Mountains. Songnen Plain and Sanjiang Plain have little forest. Heilongjiang Province is a key province for forest fire prevention in China, characterized by frequent occurrence of forest fires, big damaged area, and serious economic loss.

Forming electronic maps by using ARC/INFO

The raster-to-vector conversion method was adopted to draw electronic map, which could show factors that can be recognized by software, show maps by delamination (Peng 1998). The map of forest distribution of Heilongjiang Province is scanned with 800 dpi and saved as TIFF (Tag Image File Format), then converted to GRID format. Maps of forest distribution and administrative divisions of Heilongjiang Province are set up on the GRID pictures. The crossing point of latitude and longitude was chosen as tic point to provide bases for conversion of map. Then the ARCs were drawn on GRID pictures, and Label points are added after editing ARCs. Label points should correspond with polygons for the sake of classification. Some id marks should be held among forest types in order to append hauled-down polygons when making the map of forest distribution. After this process, the topological relation was constructed. The topology made the relation between geographical features become more concise, and some errors of digitization are easily found in topology. Correcting errors was a most important step in building database. Editing a coverage can change its topological relation, so we need frequently rebuild topological relation (Fig. 1). We classified the map of forest distribution, with addition of the attributes, and overlapped the map of administrative divisions and the map of forest distribution to form a new map layer that had the attributes of the two maps. Then the coordinates of map layer were transformed into earth coordinates. The type of projection of forest distribution map is Lambert Conformal Conic, with a central longitude of 128°E and dual standard latitudes of 46°N and 51°N respectively. The projecting process is as following: firstly, establishing a new map layer from the map layer which required projecting transform, then entering INFO database, using UPDATE PROMPT command to transform tic points into latitude and longitude, using PROJECTDEFINE command to define map layer as geographic coordinate system with longitude and latitude, using PROJECT command again to transform geographic coordinate system into Lambert Conformal Conic, and then establishing a new tic map layer again from the transformed map layer, at last, transforming the map layer into earth coordinate by using TRANSFORM command (ESRI).

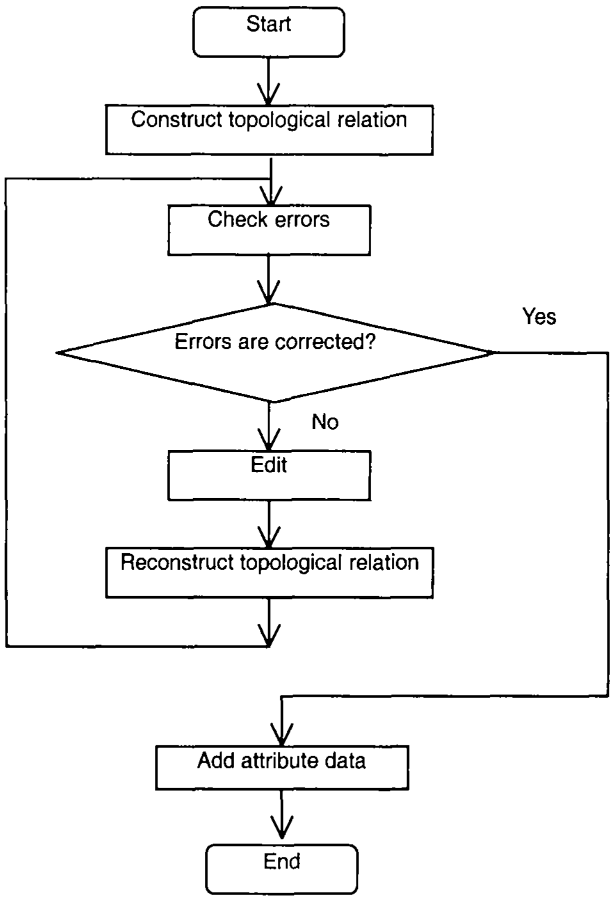

Fig.1 Flow chart of reconstructing topology.

Affecting factors of fuel type and analysis of the quantitative model

Classifying forest fuel type areas in Heilongjiang Province is to distinguish potential fire danger value of each fuel type area. In this paper, county was taken as a class unit, and the fire danger of each county was evaluated synthetically according to the assessment values of specific properties of forest resources. The fire danger rating of forest fuel for each county was divided in accordance with their potential fire danger value (D). The specific properties of forest resources are the factors that affect the occurrence and development of forest fire directly or indirectly. The main factors of limiting potential fire danger are described as follows:

$$f(D) = f(x_1, x_2, \cdots, x_n) =$$

$$a_1 f_1(x_1) + a_2 f_2(x_2) + \cdots + a_n f_n(x_n) = \sum_{i=1}^{n} a_i f_i(x_i)$$

where a_i stands for influence coefficient of factor, $f_i(x_i)$ stands for caloric assessment value of factor, x_i stands for factor of limiting potential fire danger (Yang *et al.* 1992).

The forest fuel type areas in Heilongjiang Province were divided mainly based on the factors of forest coverage, fuel load, species composition, elevation, monthly mean temperature, monthly mean relative humidity, monthly mean velocity, and monthly mean precipitation of fire season. The marks were given to each factor, and then the factors were calculated for weight. The caloric assessment value of forest fuel of each county was worked out.

The data of fuel load, monthly mean temperature, monthly mean relative humidity, monthly mean velocity, and monthly mean precipitation of fire season came from the questionnaires of national forest fire danger divisions (by the end of 1991). The data of forest coverage and species composition came from the map of forest distribution of Heilongjiang Province in 1986, and the area of forest was used to be instead of species composition. The data of elevation came from the map of Heilongjiang Province (Heilongjiang Province Bureau of Survey and Drawing, 1:750000), and practical elevation of each county was mean elevation.

In this paper, Songling and Jiagedaqi were incorporated in Songjia region. Gannan and Nianzishan were incorporated in Gannannian region. Du'erbote Mongolian nationality autonomous county is called Dumeng for short.

Forest coverage

The area of forest for the counties or cities of Longjiang, Tailai, Qiqiha'er, Dumeng, Daqing, Zhaozhou, Zhaoyuan, Mingshui, Anda, Zhaodong, Qinggang, Lanxi, Wangkui, Suihua, Suibin, Harbin, Shuangcheng was very little, nearly to zero, so that they were classified as the lowest grade of forest fuel type area.

In general, caloric assessment value should increase with forest area increasing. Caloric assessment value of forest coverage factor of a county was worked out from the following formula:

$$A = \frac{B}{C} \times 100$$

where *A* is caloric assessment value of forest coverage of a county, *B* is forest coverage of a county (%), *C* is the largest forest coverage (%).

Species composition

The coefficient of species composition is usually calculated by using cross section area and expressed by decimal ratio (represented by percentage in this paper). It also represents the ratio of forest fuel ingredients, namely the ratio of potential calorie. The difference in caloric value of species composition factor is described as the following formula:

$$y = f(x) = a_1x_1 + a_2x_2 + \cdots + a_mx_m = \sum_{i=1}^{m} a_ix_i$$

where a_i stands for the coefficient of species composition (%), x_i stands for caloric assessment value of a species (no dimension) (Yang *et al.* 1992).

Caloric assessment values of several researched stands were calculated according to wood calorific quantity, wood structure, and fire retardation (Cheng 1985; Wood Industry Institute of Chinese Academy of Forestry 1982) and referred to the data from foreign countries (Institute of Science and Technology Information of Chinese Academy of Forestry, 1981) (Table 1).

Table 1. Caloric assessment value of stands

Stands	Caloric assessment value
Pinus koraiensis	95
Broadleaved mixed forest	60
Broadleaved/Korean pine forest	70
Picea asperata Mast. and *Abies fabri*	65
Larix gmelini Rupr.	80
Pinus sylvestris var. *mongolica*	100

Fuel load

The value of fuel load was obtained from the data of national forest fire danger divisions. Heilongjiang Province includes 129 forestry bureaus in county's level. Sometimes one county includes several forestry bureaus, or one county is part of a forestry bureau. If data of a certain forestry bureau has been used to calculate caloric assessment value of a county, other counties can't use data of this forestry bureau. Theoretically, this method has no influence on the calculating result in case of calculating mean value. The similar method is used to calculate the monthly mean temperature, monthly mean relative humidity, monthly mean velocity, and monthly mean precipitation of fire season. Fuel load is calculated by the following formula:

$$y = \frac{A_1 + A_2 + \cdots + A_n}{S_1 + S_2 + \cdots + S_n} = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} S_i}$$

where *y* is fuel load ($m^3 \cdot hm^{-2}$), A_i is forestry volume of No. *i* forestry bureau (m^3), S_i is forest area of No. *i* forestry bureau (hm^2).

The woodland with small growing stock, such as open forestland, has more weeds and shrubs than that with big growing stock. The quantities of weed and shrub are usually in inverse proportion to growing stock (Yang *et al.* 1992). So the growing stock could be used to represent the quantities of weeds and shrubs. Woodland with more weeds and shrubs is likely to burn. The caloric assessment value of fuel load is worked out with the following formula:

$$A = \frac{B}{C} \times 100$$

where *A* is caloric assessment value of fuel load of a county, *B* is least fuel load (m^3), *C* is fuel load of a county (m^3).

Elevation

Below the elevation of 1 000 m, fuel is easier to dry and burn due to big wind velocity. Above 1 000 m, temperature gradually decreases with the rising of elevation and fuel is harder to burn. Mean elevation of each county in Heilongjiang Province is below 1 000 m. So the caloric assessment value of elevation of a county can be calculated by the following formula:

$$A = \frac{B}{C} \times 100$$

where A is caloric assessment value of elevation of a county, B is elevation of a county (m), C is the highest elevation (m)

Meteorological factors

Meteorological factors have important effect on the caloric assessment value of forest fuel. The monthly mean temperature, relative humidity, wind velocity, and precipitation in fire season are selected as meteorological factors. Their data come from questionnaires of national forest fire danger divisions. The meteorological factors of a county are calculated by weighted method as follows:

$$A = \frac{S_1}{S} \times A_1 + \frac{S_2}{S} \times A_2 + \cdots + \frac{S_n}{S} \times A_n = \sum_{i=1}^{n} \frac{S_i}{S} A_i$$

where A is the value of meteorological factor, S is total area of a county (hm^2), S_i is area of No. i forestry bureau (hm^2), A_i is the value of meteorological factor of No. i forestry bureau.

Monthly mean precipitation

The caloric assessment value of precipitation of a county is calculated by the following formula.

$$A = \frac{B}{C} \times 100$$

where A is caloric assessment value of precipitation of a county, B is least precipitation (mm), C is precipitation of a county (mm).

The calculating method of caloric value of monthly mean relative humidity in fire season is similar to that of precipitation.

Monthly mean temperature

The potential fire danger of forest fuel is directly related to ground temperature field. The fire danger rating increases with temperature increasing in case of the relative stabilization of other factors. So the caloric assessment value of monthly mean temperature a county is worked out by following formula.

$$A = \frac{B}{C} \times 100$$

where A is caloric assessment value of temperature of a county, B is temperature of a county (℃), C is the highest temperature (℃).

The monthly mean wind velocity has similar characteristic to that of temperature in fire season. The bigger the wind velocity is, the bigger the fire danger is. When velocity reaches the fifth grade (8.0~10.7 m s^{-1}) or above, the fire danger rating obviously increases, and occurring probability of big fire is biggest (Yang *et al.* 1992). The method of calculating caloric assessment value of wing velocity is similar to that of temperature.

Comprehensive caloric assessment value

Forest coverage, fuel load, species composition, elevation, monthly mean temperature, monthly mean relative humidity, monthly mean velocity, and monthly mean precipitation of fire season have different contributions (weight) to comprehensive caloric assessment of a county. Determining weight mainly based on two items, one was that the value of comprehensive factor should be bigger than that of single factor, and the other is that factor relatively obscures and its weight should be small (Yang *et al.* 1992). Weight of each factor is shown in Table 2.

Table 2. Weight of factors (W_i)

Factors	Weight	
Forest coverage	70	
Species composition	90	
Elevation	20	
Fuel load	20	
Monthly mean precipitation	30	
Monthly mean wind velocity	30	
Monthly mean relative humidity	30	
Monthly mean temperature	30	W=320

Comprehensive caloric assessment value of a county in Heilongjiang Province is worked out by the following formula.

$$S = \sum_{i=1}^{8} S_i W_i / W$$

where S is comprehensive caloric assessment value of a county, S_1 is caloric assessment value of forest coverage of a county, S_2 is caloric assessment value of species composition of a county, S_3 is caloric assessment value of elevation of a county, S_4 is caloric assessment value of fuel load of a county, S_5 is caloric assessment value of monthly mean precipitation of fire season of a county, S_6 is caloric assessment value of monthly mean velocity of fire season of a county, S_7 is caloric assessment value of monthly mean relative humidity of fire season of a county, S_8 is caloric assessment value of monthly mean temperature of fire season of each county.

Division of forest fuel type area

According to above results, we divided the forest fuel type areas of Heilongjiang Province into five grades by the method of cumulative probability. This method makes probability of each segment of caloric assessment value equal. Firstly, we drew the distribution map of cumulative

probability by utilizing comprehensive caloric assessment value of each county, divided cumulative probability (0～100%) into five sections: 0～20%, 20%～40%, 40%～60%, 60%～80%, and 80%～100%, which stands for the 5th, 4th, 3rd, 2nd, and 1st grade of potential fire danger respectively, and found out the corresponding value on map of cumulative probability (See Table 3). Then we labeled forest fuel type areas with different colors on the new gallery (See Fig.2, Table 4).

Table 3. S value and the potential fire danger rating

Fire danger rating	Grade Ⅰ	Grade Ⅱ	Grade Ⅲ	Grade Ⅳ	Grade Ⅴ
S	>53.6	46.4-53.6	41.7-46.3	38.3-41.6	<38.3

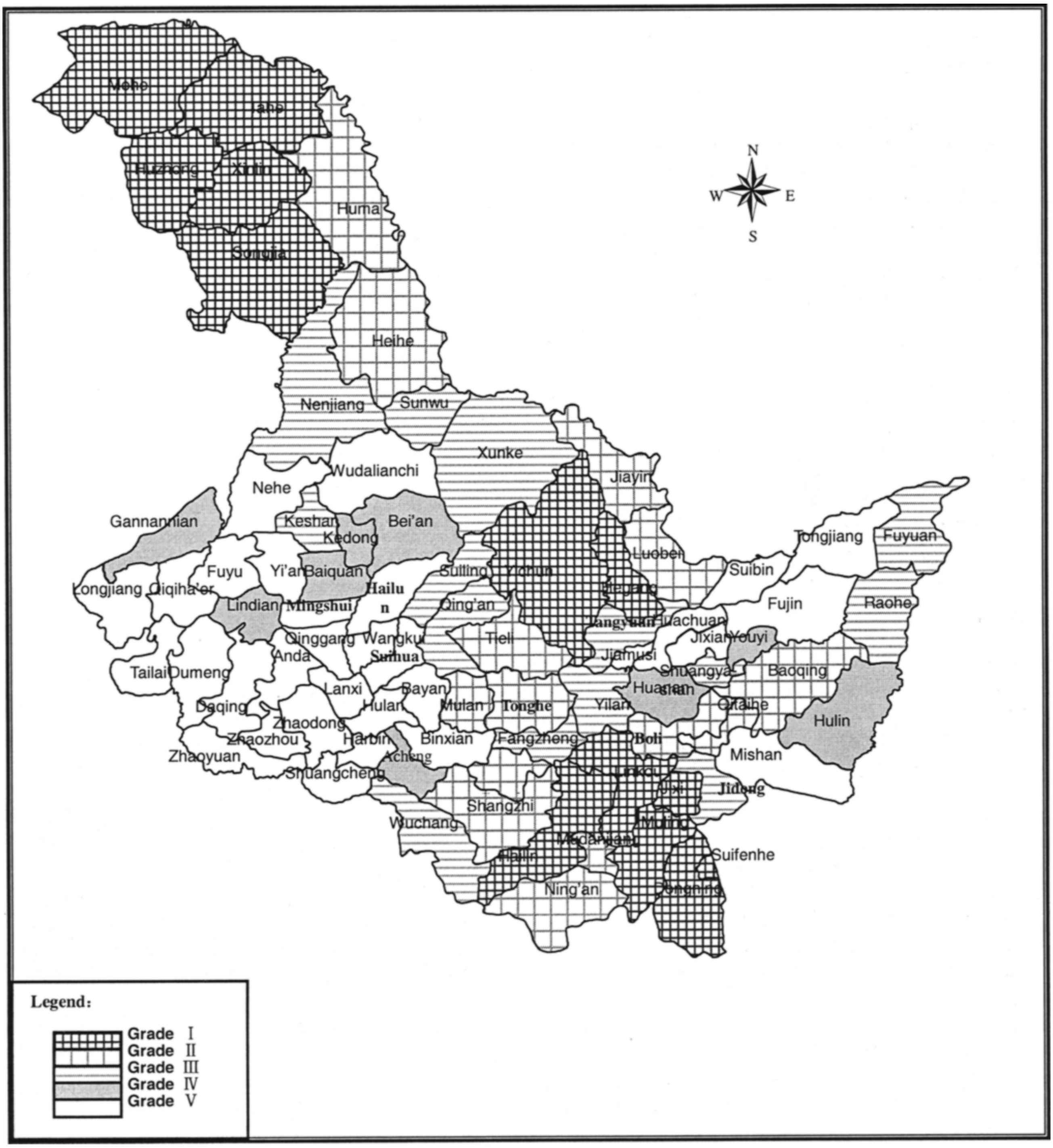

Fig. 2 Forest fuel type areas of Heilongjiang Province

Table 4. The potential fire danger rating of forest fuel in Heilongjiang Province

Fire danger rating	Counties and cities
Grade Ⅰ	Mohe, Tahe, Huzhong, Xinlin, Songjia region, Yichun, Hegang, Jixi, Linkou, Hailin, Muling, Suifenhe, Dongning
Grade Ⅱ	Huma, Heihe, Jiayin, Tieli, Luobei, Baoqing, Boli, Qitaihe, Mudanjiang, Ning'an, Mulan, Tonghe, Yanshou, Shangzhi
Grade Ⅲ	Nenjiang, Sunwu, Xunke, Keshan, Qing'an, Suiling, Tangyuan, Fuyuan, Shuangyashan, Raohe, Jidong, Yilan, Fangzheng, Wuchang
Grade Ⅳ	Bei'an, Gannannian, Kedong, Baiquan, Lindian, Huanan, Youyi, Hulin, A'cheng
Grade Ⅴ	Wudalianchi, Nehe, Fuyu, Yi'an, Hailun, Jiamusi, Huachuan, Gujin, Tongjiang, Jixian, Mishan, Hulan, Bayan, Binxian, Longjiang, Tailai, Qiqiha'er, Dumeng, Daqing, Zhaozhou, Zhaoyuan, Mingshui, Anda, Zhaodong, Qinggang, Lanxi, Wangkui, Suihua, Suibin, Harbin, Shuangcheng

Conclusions

Based on forest coverage, fuel load, species composition, elevation, monthly mean temperature, monthly mean relative humidity, monthly mean wind velocity, and monthly mean precipitation of fire season, forest fuel type areas of Heilongjiang Province including 81 counties were divided into five grades by the methods of the weight and the cumulative probability, 13 counties in grade Ⅰ, 14 counties in grade Ⅱ, 14 counties in grade Ⅲ, 9 counties in grade Ⅳ, and 31 counties in grade Ⅴ, and they accounted for 16%, 17%, 17%, 11%, and 38%, respectively. The grade Ⅰ forest fuel type area mainly distributed on Daxing'anling Mountains, Xiaoxing'anling Mountains, and Zhangguangcailing Mountains, and the grade Ⅴ forest fuel type area mainly focused on Songnen Plain, Sanjiang Plain and other plains, other forest fuel type areas (grades Ⅱ, Ⅲ, and Ⅳ) were situated between plains and mountainous areas.

Electronic maps of forest distribution and administrative divisions for Heilongjiang Province were built by the method of raster-to-vector conversion. This offers basic data of gallery for studying the forest, fire danger and other statuses of Heilongjiang Province.

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